Fuel Flexible Gas Turbines for Sustainable Power Generation

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Outline

• Introduction
• Fuel Flexibility Options
  ✓ Liquefied Natural Gas (LNG)
  ✓ Syngas
  ✓ Oils
• OpFlex™ Model Based Controls
• Summary
Introduction
Hydrocarbon consumption 2011
~85% of primary energy

Hydrocarbon consumption, 2011
Million Tonnes Oil Equivalent

10,522 Total

North America
China
Europe
Middle East
Eurasia
OECD Asia
India
Other Non-OECD
Latin America
ASEAN
Other OECD
Africa

Source
Coal
Gas
Oil

Million Tonnes Oil Equivalent, 2011
Industry drivers for fuel flexible solutions:

- Diversified power generation mix (in terms of both fuel sources & suppliers)
- Greater energy independence/autonomy
- Efficient use of energy/emissions

Fuels experience ... broad range
LNG & Natural gas variation
LNG & Natural gas variation

Gas composition variation will increase as more LNG is injected into pipelines

Variation poses gas turbine operability challenges

- Auto-ignition
- Flashback
- Combustion dynamics
- Combustor lean-blowout
- Emissions compliance ($\text{NO}_x$, CO)

Addressed by OpFlex* offerings

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<tr>
<th>Constituent</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>Nitrogen (N2) [%]</td>
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<td>0.4</td>
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<td>Carbon-Dioxide (CO2) [%]</td>
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<td>Methane (C1) [%]</td>
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<td>Ethane (C2) [%]</td>
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<td>Propane (C3) [%]</td>
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<td>Iso-Butane (IC4) [%]</td>
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<tr>
<td>n-Butane (NC4) [%]</td>
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<td>Iso-Pentane (IC5) [%]</td>
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<tr>
<td>LHV [BTU/scf]</td>
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Syngas
Syngas production in an IGCC plant

Gasification

Partial oxidation

Solid feedstock is gasfied

H₂ & CO (syngas)

Gas clean-up

Gas Turbine

MNQC Combustor Diluent (N₂, Steam)
Syngas to hydrogen (CO$_2$ separation)

1. **Gasification**
   - Partial oxidation
   - Solid feedstock is gasfied

2. **“Shift” Process**
   - Steam/Syngas Reactor
   - Catalyst based Water-Gas converts CO to CO$_2$

3. **CO$_2$ Capture + Compression**
   - Acid Gas Reactor system removes CO$_2$, which is compressed and piped off-site

4. **Gas Turbine**
   - MNQC Combustor
   - Diluent (N$_2$, Steam)

- **Partial oxidation**
  - CO + H$_2$O $\rightarrow$ CO$_2$ + H$_2$ (H$_2$ rich syngas)

- **EOR or Storage**
  - H$_2$ & CO (syngas)
Syngas turbine controls and accessories

- Inlet filter house
- Inlet duct & plenum
- Gas fuel module
- Water injection skid
- Exhaust system
- Static starter
- IGCC Controls with added I/O
- Controls hardware and software
- Accessory module
- Liquid fuel and atomizing air
- Syngas fuel skid with N2 purge
- Optional air extraction skid*
- Enclosure modifications:
  - Piping for syngas, diluent, etc.
  - Explosion proofing
  - Hazardous gas detection
  - Fire protection
- N2/Steam injection skid*

*Fuel and diluent skids/modules may need to be customized for specific fuel/plant configurations
MNQC for E/F Syngas Turbines

- MNQC (Multi Nozzle Quiet Combustor) – Diffusion (Not DLN)
- Same combustor architecture for 6FA, 7EA, 9E, 7F Syngas, and 9F Syngas turbines
- End cover/fuel nozzle assembly nearly identical, except for minor scaling
- Combustor liner and cap designs similar, scaled to different operating conditions
- Diluent N₂ or Steam or a blend
- Air extraction available for integration with process
Oils
Biofuels field tests ... ready when opportunity is right

Biodiesel
• Fuel used met ASTM D-6751 & GE liquid fuel specification
• Operated from start-up to full power on a range of fuel mixtures
• Confirmed that NO\(_x\) emissions were comparable to turbine running on distillate fuel

Ethanol
• Successful test performed on a 6B Gas Turbine in 2008
• Commonalities with naphtha: high volatility, poor lubricity, miscible

6B Gas Turbine—standard combustor
Fuel: B20 – B100
Fuel: Ethanol

7EA Gas Turbine—DLN1 combustor
Fuel: B20 – B100

LM6000* SAC
Fuel: B100

* LM6000 is a trademark of General Electric Company.
Crudes ... decreasing OpEx; increasing availability

Shift to heavier oils and sour gas
• Field reserves and refinery ends
• Leads to corrosion, ash deposition and emissions concerns
• Impacts CapEx (Capital Expenditure) and OpEx (Operational Expenditure)

Technical solutions ... Heavy fuel oil (HFO) availability package
• 4 key attributes
  – Smart cool down
  – Automated water wash
  – Model based control
  – Open S1 nozzle
• Decreases offline time to perform water wash (from 48 to <16 hours)
• Reduce degradation and maintain Tfire ...
  25% reduction in output degradation rate
• More power, better efficiency

Sulfur concerns:
• Acidity of oceans environmental standards

Heavy Metal concerns:
• Preventing vanadium corrosion
• Efficiency/maintenance impact

MBC firing temperature control

Maintain base load Tfire

Recoverable performance zone

Traditional Tfire

Operating time between turbine washes
OpFlex™ Model Based Controls
OpFlex™ Model Based Controls Overview

Today: Indirect (Tx Space) Boundary Control

- Approximate Boundary Protection
  (Calculated Off-line to Accommodate Worst-Case Condition)
- No Explicit Accommodation Of Machine Deterioration
  (New & Clean / Mean Machine Assumption)
- Coupled Effectors Prohibit Optimization
  (Part-Load Exhaust Temperature & Fuel Splits)

Model Based Controls : Direct (Boundary Space) Boundary Control

- Direct Boundary Protection
  (In The Boundaries Physical Space)
- Accommodation Of Machine Deterioration
  (Adaptive Model Ensures Accurate Surrogates)
- Implicitly De-Coupled Effectors
  (Automatic Performance Optimization)
- Robust / Flexible / Expandable
  (Additional Boundaries / Loops)
- Proven GT Control Technology
Model-Reference Adaptive Control

Boundary Scheduling Logic

Commands

Boundary Targets

Errors

Model-Based Control Structure

(Loop Selection Logic)

Effectors

Gas Turbine

Combustion Dynamics Measurement

TF Tuning

Estimated Boundary Levels

Surrogates

ARES - Parameter Estimation

Engine Model

Boundary Transfer Functions

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Fuel Flexibility with OpFlex™ MBC

Model-Based Control

Prioritized Dynamics Control
1\textsuperscript{st}: Fuel Splits
2\textsuperscript{nd}: Fuel Temperature
3\textsuperscript{rd}: Load Reduction

Combustor Capability Unleashed

Wide Wobbe

Fuel Flexibility
(Simulated +/- 10% WI over 30sec)

Wide-Wobbe Capability

GEI-41040
±5\%
7FA

±20\%
9FA

Modified Wobbe Index (MWI)

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Automated DLN Tuning with OpFlex™ MBC

- LNG terminal less than 200 km from 207FA combined-cycle power plant
- LNG storage tank originally purged with CO₂ ... not all CO₂ removed before LNG was introduced to tank
- CO₂ / LNG entered pipeline and reached site at 11:24 am
- Initial Modified Wobbe Index (MWI) value decreased 5.6% due to presence of CO₂ in fuel
- MWI increased 8.7% due to LNG
- Maximum rate of change in MWI reached 9.5%/minute
- Modular control maintained acceptable emissions and dynamics levels throughout event
Summary

- Regional trends, design/operational constraints and fuel availability will continue to drive the power generation industry towards non-traditional fuels.

- Gas turbines have demonstrated capability to operate on a wide variety gaseous and liquid fuels.

- GE has successfully tested/operated many of these fuels and decreased OpEx and CapEx impacts to the heavy duty gas turbine ... goal is for performance like it is operating on natural gas.

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Thank You. Questions?
imagination at work